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Soil resources and land use in south-western Australia

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Abstract

Field studies of soils and their distribution in Australia generally, and in south-western Australia in particular, are briefly reviewed, and the influence of similar studies in Russia and the United States of America indicated. The significance of field studies of soils in south-western Australia is discussed in relation to the assessment of soil resources for land-use planning. In this context, the argument is advanced that the landscape as a whole, together with the biological and physical processes taking place within it, is a more useful frame of reference than the traditional soil profile only a metre or two deep. Land-use planning in south-western Australia, in regard to forestry, farming and water supply, is considered. The conclusion is reached that the benefits of increased knowledge and understanding of soils and other environmental factors are unlikely to be fully realised in the absence of an effective regional planning machinery.

Introduction

I am concerned, in this address, mainly with field studies of soils in Western Australia, as they relate to land use; i.e. with the implications of soil distribution and characteristics for land-use planning and management. I shall not be dealing with, for example, specific studies of plant and animal nutrition related to trace element and other nutritional deficiencies, where pioneer workers like L. J. H. Teakle, T. C. Dunne and E. J. Underwood have made such substantial contributions. Nor shall I be considering the important studies of the fundamental physical chemistry of soils and minerals of A. M. Posner, F. J. Hingston, J. P. Quirk and others. Instead, my subject is the landforms and soils mainly of south-western Australia, and some of the soil and landscape properties and processes relevant to our use of the land. A principal objective of such studies is, of course, a contribution to the technical basis of rational use of the land through the understanding and assessment of soil resources.

Assessment of soil resources

The assessment of Australia's soil resources began with the early explorations, and they were often highly optimistic. We may contrast Captain Stirling's reports on the agricultural potential of the proposed Swan River Colony with the subsequent difficulties encountered in establishing a viable agriculture: or, in more recent times, there are the hardships and miseries suffered by the group settlers in the South-West, whose story has been told so well by Geoffrey Bolton in "A Fine Country to Starve In" (Bolton 1972). The optimism was often due to ignorance of technical problems, many of which we now recognise. So it is not surprising that, as a more scientific and technical approach developed, soil scientists did not always share the enthusiasms of their governments. Many of you will remember the late L. J. H. Teakle, whose assessment of the risks of soil salinity in a large area of virgin land south of Southern Cross led to the ambitious "3500 Farms Scheme" being dropped in the 1930s (Teakle 1939). That experience, which we are well placed to appreciate in the light of today's problems, emphasises the need for systematic and objective assessment of our soil and land resources.

I do not, of course, mean to suggest that an assessment of soil and land resources ought to be the sole determinant of decisions with regard to agricultural and other developments. Clearly, social, economic and political factors are also involved. But they should not be allowed to obscure the technical difficulties which may be inherent in the nature of the resources themselves.

Overseas examples

The development of scientifically based studies leading to assessment of Australia's soil resources was, of course, influenced by experience elsewhere, particularly in Russia and the United States of America.

The Russian experience

Soil scientists are familiar with the principles developed by Dokuchaev (1883) and his colleagues in Russia about the middle of last century. They included the concept of Great Soil Groups and their distribution over the land mass of European Russia according to climatically defined zones. Terms like podsol, brown forest soil, black soil and solonetz became widely known and used in many countries beyond Russia. What is not so widely appreciated is that the work of Dokuchaev and his colleagues was

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in response to a need for an exploratory assessment of land resources and their potential productivity over a vast continent. Because of the practical difficulty of effective observation over large areas, the philosophy of the approach was prediction of soil conditions on the basis of known or assumed relationships with environmental factors, particularly climate. There must have been a degree of success, since the Russians were confident enough to go further and produce, between wars, a soil map of the world, based on those relationships. While it was a valiant effort, it has serious defects, particularly in respect to Australian soils, which, as I shall discuss later, are much more conditioned by past climates than those of the present.

The Russian scientists showed that the forest soils of the northern cool temperate zones, with abundant rainfall, formed over glacial or periglacial deposits with an abundance of fresh minerals. Thus they had an inherent capacity to replenish losses caused by productive use of the soil as those minerals weathered. They are subject to leaching losses of bases and nutrients, and waterlogging, so that liming, fertilisation and drainage are the main ameliorative measures required.

The soils of the drier, warmer grasslands, e.g. the black soils of the Ukraine, with a similar mineral-rich substrate, but less subject to leaching, had high natural fertility and a more readily sustained productivity. Expansion of agriculture on such soils, as they extend into lower rainfall country on the Siberian Plains beyond the Ural Mountains, is still in progress. A rather mystical or sentimental faith in the inherent productivity of the Russian chernozem or black soil was responsible for delays in developing the fertilizer technology necessary for the higher levels of production which are possible.

In the humid tropics the Russians predicted deep weathering and deficient mineral substrates, with short-lived high initial fertility in the surface organic layers built up by the indigenous forests, and a lower capacity to restore the losses through further mineral weathering. They recognised salinity problems in semi-arid and arid areas.

Such a conceptual framework rationalises the history of agricultural development. The northern forest lands and the drier and warmer grasslands became the permanent farmlands of Europe and eventually the United States. The earlier intensification of agriculture in the dry Middle East and wet tropical Asia depended on the alluvial plains of the great river systems such as the Nile or the Ganges. Their flood waters, loaded with sediments, both replenish fertility and make irrigation possible, provided that an appropriate technology can be developed and maintained.

The Russian approach, brought to Australia by J. A. Prescott, was the basis of the first soil map of Australia, published with his bulletin "The soils of Australia in relation to vegetation and climate" (Prescott 1931). It was an important and most useful compilation in its day. The difficulties overcome in gathering the information must have been formidable, in the absence of today's rapid and easy transport, with few reliable maps or air photographs and no such thing as satellite imagery. Prescott's map was the beginning of many attempts to systematise the information being gathered piecemeal throughout the continent by land surveyors, government chemists and the like, and stimulated Teakle's early soil classification work in Western Australia and the many soil surveys under his direction (Teakle 1938).

The United States experience

At about the same period, the American situation resembled the Russian in that there was a need for an exploratory assessment of soil resources. While surveys began with simple attempts to classify soils on the basis of the geology of parent materials and the assessment of fertility by chemical analysis for nutrient elements, the Americans too were later influenced by the Russian concepts. Again, the particular appeal of these concepts lay in soil-environmental factor relationships as a basis for understanding and predicting soil characteristics over large areas (Marbut 1927). However, there remained, as well, a preoccupation with detail, often unguided by principle, whether scientific or use-orientated. Faith in a technology fueled by abundant cheap energy, and a lack of appreciation of the need to protect the complex soil biological systems led to severe erosion problems prior to the establishment of the United States Soil Conservation Service. This experience too has had its influence on the Australian approach.

Australian conditions

There are some important differences between Australian conditions and those in Europe and North America from which example and experience could be drawn. There the new areas being explored and developed were characterised by soils which were often naturally highly productive, and many other environmental factors were similar to those in the longer settled European areas from which the pioneering effort came.

In Australia the conditions were, and are, vastly different, particularly I would suggest in respect of geological history, superficial geology and consequently the soil parent materials. In Australia, the superficial deposits and deep-weathered profiles are quite unlike those of the countries from which the settlers came. This is especially so in Western Australia, where the Precambrian Shield is relatively unaffected by earth movements that have affected other parts of the world, including eastern Australia. It has thus, to a great extent, not been subjected to the erosional and depositional processes brought about elsewhere, which have destroyed older landscape elements and their associated weathering products and soils (Mulcahy 1961). The Permian and younger sediments, representing the shallow seas which once separated Western Australia from the rest of the continent, lie relatively undisturbed beneath the deserts that still separate us almost as effectively.

In other words, the landscape is a very old one. Johnstone *et al.* (1973) suggest that its main form in south-western Australia, with a drainage system "whose relics are the chains of salt lakes seen today", was established by the late Jurassic to early Cretaceous. If this is true, then it has survived since before the Gondwanaland continents drifted apart, and during the earth movements which formed the Alps and the Rocky Mountains. Much later it escaped the more drastic effects of the ice ages which in Europe and America ground away the old soils, and laid down fresh materials on which new and more fertile soils could form.

In another important respect, conditions in Australia are also very different. In Europe and North America, where there are many more and longer established research institutions, soil scientists are well served in respect of knowledge of the superficial geology from the work of Pleistocene stratigraphers, geomorphologists and geologists. Here in Australia we are not so well aware of the nature, let alone the extent, of the superficial deposits and weathered mantles which form the soil parent material, and the soil scientist has had to undertake their investigation for himself. Some interesting work has been done as a consequence, which I cannot review here, but have discussed elsewhere (Mulcahy and Churchward 1973).

Soils of south-western Australia

Soils with such a long history as those of south-western Australia must have experienced a wide range of climatic conditions, and consequently a close correlation between soil and present day climatic zones would not be expected. Indeed, extremely weathered profiles and leached soils normally associated with the humid tropics are widespread in Western Australia generally, extending far beyond the present high rainfall areas into the semi-arid and arid regions. They are generally of low fertility, due to deficiencies of nutrient elements, both major and minor. Applied nutrients, particularly phosphorus, may be fixed in forms unavailable to plants, or alternatively, lost by leaching from the coarse-textured surface sands. These soil properties are characteristic of tropical and arid areas of many of the underdeveloped countries.

The old soils of south-western Australia, inherited from past periods in geological time, have not survived completely unchanged until the present day, though they do carry the marks of their history. Perhaps I can best illustrate this and at the same time give some indication of advances in knowledge over the last forty or fifty years by a comparison of Prescott's 1931 soil map of Australia, with the more recent atlas of Australian soils (Northcote *et al.* 1967), a simplified form of which has been produced by Mulcahy (1973).

While Prescott's map recognised the great extent of the leached lateritic soils in the drier areas, and referred to them as "fossil" soils markedly influenced by past climates which were warmer and more humid, his map nevertheless shows the influence of the Russian approach in that his boundaries tend to align themselves with the boundaries of climatic zones. In contrast, the later map, based on more detailed information, shows superimposed on this a relationship between soil distribution and the drainage system. It reflects also the modifications of the old landscapes by the processes of subaerial erosion and deposition which have acted over time to produce a complex landscape and soil pattern, the main features of which are:

(1) The salt lake chains of the interior clearly have a riverine form, draining both westwards to the coast, and eastwards to terminate in the shallow marine sediments of the Nullarbor Plain. These are the relict drainage systems already referred to, and shown in Figure 1.

(2) The now sluggish and ineffectual drainage system represented by the salt lake chains ceases abruptly in the west along the Meckering Line (Fig. 1), named after the town through which it passes. Downstream of that line, there is a closer, more incised and effective network of streams. This change in land form bears a fascinating geographic relationship to the zone of seismic activity associated with the Yandanooka-Cape Riche lineament (Everingham 1968) running along the line of the Avon Valley and the Great Southern railway line, a little to the west. This raises the suggestion, which is of course not new (Penck 1953), that the nature of the landforms, and in this case also the distribution of the soils, reflects the tectonic history of the continental margin. It seems that only in the limited areas where there has been tectonic activity has the landscape sufficient relief to enable erosional processes, acting over geological time, to create new surfaces of any significant though limited extent. Here too are the limited areas of naturally fertile soils which were the basis of the State's earliest agricultural development.

(3) The source of the salts accumulating in the landscape, most obviously in the salt lakes, is as a dilute solution in the water falling as rain. Nevertheless the amounts received are large, ranging from 150 kg/ha. yr, mainly NaCl, near the coast to 30 kg/ha. yr in the interior (Hingston and Gailitis 1976). Only about 10% is found in the salt lakes, the remainder, amounting to 10^6 kg/ha or more, is in the deep subsoils (Dimmock *et al.* 1974).

(4) Lateritic sandplain soils are extensive inland of the Meckering line, and both they and the valleys of the salt lake chains are underlain by very deep (30 m or more) zones of extremely weathered sandy clays, often called 'pallid zone' because of their pale colour. It is in this part of the profile that much of the salt accumulates. The surface sands are deficient in N and P, and also the trace elements Cu, Zn and Mo. They may also fix much of the phosphate applied as fertiliser in unavailable forms. Thus agricultural development was impossible on them until the problems were understood and suitable fertiliser technology developed.

(5) The western and south-western areas are dominated by lateritic ironstone gravel soils, often bauxitic, typically in the Darling Range. They also are underlain by deep pallid zones, but here, especially in the higher rainfall areas nearer the coast, salt storage is lower, despite the higher input, due to more effective leaching. The soils share the nutritional problems of the sand plains. This, and high clearing costs due to heavy timber, prevented early clearing for agriculture thus fortunately preserving the forests with their role in protecting the water resources.

(6) The surface soils of the sandplains and bauxites transmit water rapidly, due to their coarse textures. The underlying clays of the pallid zones tend to have low transmissivities (Hurle and Johnston 1979), except where formed over more sandy parent rocks such as the Permian sediments of the Collie coal basin. In the latter case, levels of salt storage in the profile tend to be lower.


GERALDTON
MECKERING
COOLGARDIE
SCARP
NORTHAM
PERTH
LINE
NARROGIN
BUNBURY
DARLING
KOJONUP
ALBANY
Uncleared Land
Cleared Land
Drainage
Salt Lake Chain
0
150 km
SCALE

(7) Between the extensive sandplain areas and the lateritic or bauxitic ironstone gravel soils, is a zone of incised and effective drainage, where the lateritic sands and gravels crown the divides and spurs; exposed pallid zone and other preweathered material lies on the slopes below, and fresh rock as a soil parent material is occasionally exposed in the more deeply and sharply incised valleys.

(8) Widespread removal of the lateritic materials to give younger, more fertile soils is thus found only in more incised valleys, such as that of the Avon near York and Northam, or the Blackwood at Bridgetown.

(9) Fine-textured, silty, saline and calcareous soils appear to be associated with the salt-lake chains, and are believed to be, at least in part, due to wind action, which has blown loess-like materials with these characteristics from the lake floors when dry, to blanket country downwind, generally to the east and south-east of the postulated source (Bettenay 1962). Killigrew and Glassford (1976) suggest that kaolin spherites in sand plain deposits are also aeolian in origin, from a source in fluviatile sediments.

In summary, then, due to its history, the landscape is characterised by a great extent of extremely weathered materials, which may, in some cases, have been transported some distance from their source. The soils developed on them are of low fertility—the sandplains, laterites, and bauxites—and hence of low biological productivity in their natural state. They have, due to their great depth, a great capacity to store water. The extreme and deep weathering indicates the loss of much of the original mineral constituents and their movement out of the landscape through a drainage system which, in the past, must have been more effective than it is today. It also indicates that the accumulations of soluble salts now found deep in the soils must have taken place following the weathering, which required effective leaching and removal of such soluble materials. At present day rates of accession, the salts could have accumulated in a relatively short period, say, a few tens of thousands of years (Dimock *et al.* 1974).

Soils and land use

Until 150 years ago, south-western Australia was occupied by Aborigines whose systems of land use were adapted to the low levels of biological productivity resulting from the nature of the soils. Thus their levels of consumption were also necessarily low, since there was little external trade, and little opportunity to import. The ways in which they took their living from the land were, nevertheless, in a stable equilibrium with their environment, as shown by the survival of aboriginal cultures for many thousands of years. Even so, in reaching such a state they may well have been a substantial modifying factor. Indeed, Dr. Merrilees entitled his Presidential Address to this Society in 1967 "Man the Destroyer", since he believed them to have contributed to the extinction of a number of species now known to us only through their fossil remains (Merrilees 1968). European settlement brought an end to isolation, and introduced a society with expectations of higher levels of consumption, and a much greater ability to modify the natural environment, and to extract and produce from it. There followed the development of an agricultural technology dependent on the restoration of the soil fertility lost through long continued weathering by imports of fertiliser, and through the introduction of legumes compatible with European style agriculture. The rate of agricultural development and its productivity was later increased by the availability of machinery and the fuel to drive it. Discovery of gold and other minerals, and the export of timber, supported the economy in the meantime. Now income derived from such forms of primary production supports an affluent and consumer orientated society, generates capital, and attracts secondary industry.

The impact of these developments on the land resources is, of course, considerable. We are still seeking a new, stable balance between these increased levels of human activity, and the natural environment, which must minimise irreversible adverse effects if our society is to survive in the long term. It can hardly be argued that this has yet been achieved, in view of the disturbed salt and water balances of agricultural areas and catchments, the declining productivity of pastoral areas, the unhealthy condition of much of the jarrah forest, and the paucity of conservation reserves, particularly in the wheatbelt. Let me briefly mention some of the principal problems of our main rural land uses, forestry, agriculture and water supply.

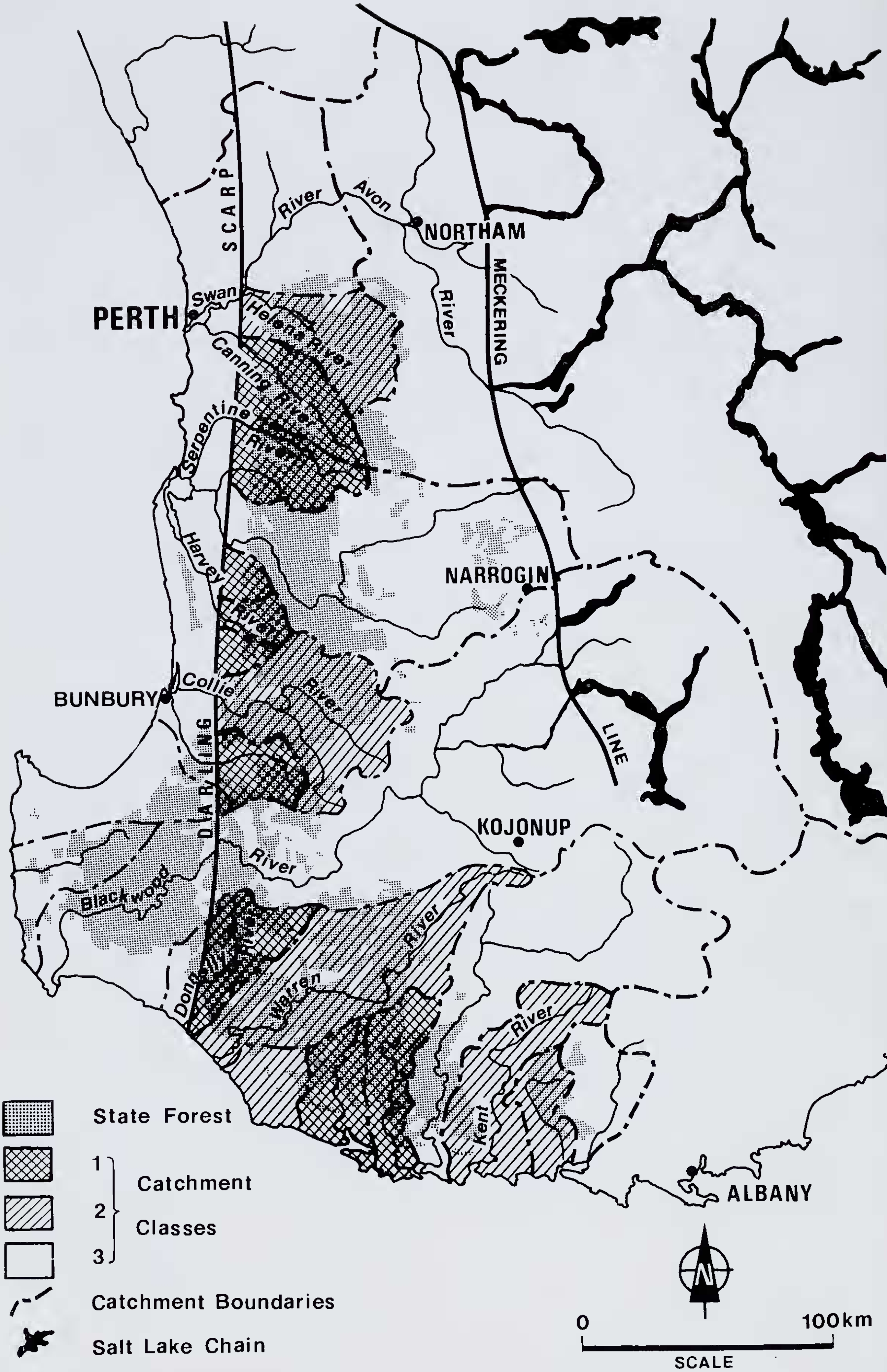
Forestry

The native hardwood forests of the South-West are uniquely adapted to their peculiar environment, in ways which research workers and forest managers are just beginning to understand. These mechanisms enable the forests to grow on the extremely deficient soils and survive the rainless summers. Substantial areas have been lost to agriculture, others to urban, residential and industrial development, and the full impact of open-cut mining is yet to be determined. Protection of water resources and the use of forest areas for public recreation are now recognised as having as high a priority as wood production, and good management could increase the potential values of both.

Most of the forest area has been cut over at least once, and some of it successfully regenerated, but it is threatened by disease, and the risks are heightened by all these increased levels of human activity. It is likely that the demands for wood products will rapidly increase in the future, in fact the demand for increased production is probably already here. Woodchips are exported from the karri areas, and increases in energy costs, together with improvements in harvesting technology are likely to put further pressure on the jarrah forest for wood and other products for fuel. Intensification of production and export of nutrients may be expected to involve risks of long-term loss of biological productivity of ecosystems growing on such extremely deficient mineral substrates.

These developments can be seen either as a threat, or as an opportunity. I prefer the latter alternative. Provided that adequate conservation areas are established, the income derived, or anticipated, from increased production of commercial value of both

Figure 1.—Drainage systems of south-western Australia.



PERTH
NORTHAM
NARROGIN
BUNBURY
KOJONUP
ALBANY
DARLING SCARP
MECKERING LINE
Avon River
Swan
Helena River
Canning River
Serpentine River
Harvey River
Collie River
Blackwood River
Donnelly
Warren River
Kent River
State Forest
1
2
3
Catchment Classes
Catchment Boundaries
Salt Lake Chain
N
0
100km
SCALE

wood and water could provide the funds for the intensification of management which will be necessary if the forest is to be maintained and protected.

But such management will depend on predictions based on understanding, consequently research on the functioning of the forest ecosystem assumes a high priority.

Agriculture

Agriculture has been one of Western Australia's success stories, culminating in the late sixties with "a million acres of new farms a year". The scientific work in support of agricultural development has been purposeful and effective, though unfortunately I cannot review it here. Yet there are still the adverse effects of salinisation of soils and water supplies, due to the failure of our present agricultural systems to use soil water as fully as did the native plant communities which they replace. (Mulcahy 1978). While there is considerable interest, and a great deal of experimental work on the effects of reafforestation, screening of suitable tree species for the purpose, and on revegetation of saline soils, so far I do not believe that a purposeful effort is being made to modify agriculture in ways that will use the water where it falls, so that catchment salt and water balances may be restored and adverse effects on water resources and soils avoided. The present array of agricultural plants results from 150 years of introduction, selection and breeding, with the objective of producing crops and pastures which can complete their cycle of germination, growth, flowering, and seed setting before the moisture available in the surface soil is exhausted. Thus the risk of failure to complete the growth cycle in a dry season is minimised, an obvious advantage to the farmer. Long-term research on agricultural systems should now aim at finding agricultural plants, perhaps perennials, which would use more water from greater depths. Increased water consumption by as little as 10% might suffice, but this must be at the cost of greater risk of failure in a low rainfall season, though it might be offset by a greater potential for production in good seasons.

Water Supply.

That water supply can be affected by other land-use practices is clear from what I have already said. The phenomena outlined are the basis for a classification of catchments and the discussion of their management (Sadler and Williams 1979). Essentially it depends on the extent of a catchment beyond State Forest, or inland of the 800 mm isohyet, into predominantly agricultural land and on whether the headwaters tap the inland salt lake systems.

Three groups of catchments may then be identified (Fig. 2):

Class 1 catchments are those of rivers rising almost completely within forest areas. Water yield is high, quality good; several rivers are already harnessed for water supply and others are likely to be in future.

Class 2 catchments are those of rivers which extend beyond the forest into agricultural land in their headwaters, but do not tap the salt lake systems. Yields are still high, but quality has been affected by clearing. Several are dammed, and the others may be developed in the future.

Class 3 catchments are the most extensive, between them draining about two-thirds of the agricultural areas. Several of them, notably the Swan-Avon and the Blackwood, tap the salt lake systems (Fig. 2) which have been known to flow as an entire system in exceptionally wet years. Their yield is high but is generally of poor quality, being either brackish or saline. It should be noted, however, that certain of their downstream tributaries could well qualify for Class 2, and a few for Class 1.

Of the three classes, only 1 and 2 are seriously considered for water supply development. Of the two, those in class 1 are clearly the most valuable on grounds of both yield and quality. In general, land use is strictly controlled on them, since they lie mainly within State Forest, where management policies give high priority to conservation of the water resource. Bauxite mining is in progress there with removal of the permeable surface soil bringing the less permeable subsoil clays much closer to the new land surface. This can lead to downstream effects on wetlands and on stream courses due to changes in catchment characteristics. It can result in more rapid and frequent run-off events of shorter duration, and an increased risk of salinisation in lower rainfall areas.

The class 2 catchments are the really pressing management problem, so much so, that the State has very recently moved to establish controls on the clearing of privately owned land within them, with the principal objective of preventing further clearing in the lower rainfall parts. There are significant areas of as yet uncleared land on many farms in these lower rainfall head-water areas, which, if developed for agriculture, would lead to further deterioration in water quality. The controls, which involve compensation payments, are administered in accordance with guidelines which reflect the variation and interaction of the soil, rainfall and other factors, and their effects on the subsurface hydrology.

Discussion

Traditionally, soil science concerns itself with the soil profile, usually only a metre or two in depth, its characteristics and the processes going on within it. Yet it would seem that the land-use problems discussed here call for more than this, involving the characteristics and processes of the landscape as a whole.

For general purposes a study of functional relationships within the landscape rather than just within the soil profile is required. It will be particularly important in respect of the movement of water and solutes in the superficial deposits and weathered profiles which in many cases form shallow aquifiers, and in which soluble salts are stored. These hydrologic systems can be readily modified by agricultural and

Figure 2.—Surface water catchments in south-western Australia. See text for explanation of catchment classes.

other land uses (Bettenay *et al.* 1964). Kovda *et al.* (1968) show the importance of such relationships and their changes over time in investigations or regional geochemistry, with potential application in mineral exploration. They are fundamental to the interpretation of studies of forested catchments, whether they are concerned with the effects of management on nutrient losses and long term productivity (e.g. Bormann *et al.* 1974), or on water yield and quality (Shea *et al.* 1975). Such functional relationships in landscapes have long been part of the thinking of some soil scientists like Milne (1947) and Glentworth and Dion (1949), though they too were mainly concerned with the surface soil profile. But the surface soil is only part of the natural system to be managed. Flows of water, nutrients and energy are likely to be more usefully studied in the frame of reference of the landscape and the ecosystem; geochemical and mineralogical differentiation takes place, not only in the surface soil but in the landscape as a whole.

Conclusion

Underlying what I have said in discussing the land use problems of south-western Australia, is the clear implication that growth and development is forcing the State of Western Australia towards a situation in which there is an increasing degree of competition for the use of the land resources even in rural areas. Forests have to afford recreation and produce water as well as timber; farmers are beginning to have to accept restrictions on what they may do on their own properties, while good farmland is being lost to residential and industrial uses. Greater appreciation of the conservation and recreational value of natural areas, for which there are still great opportunities in Western Australia, is also an important factor (Department of Conservation and Environment 1981).

The change from a pioneering State, with its "one million acres of new farms a year" to one in which Crown land releases for agriculture have been restricted and forest clearing controlled, has taken place in just about one decade. The community has to accept that areas of land can no longer be devoted exclusively to single uses, and the constraints involved in this. But to do so the public generally needs a broad general understanding of the complex natural systems and their responses to management, and it is desirable for this to be brought about quickly. While the sort of understanding required is growing among engineers, foresters, agriculturalists and other professionals involved in natural resource management, it is uncommon among people generally. Perhaps we need an extension service for the purpose, as well as those already in existence, which tend to provide advice for single uses such as farming or private pine plantations. If this were established then an informed public opinion could have proper influence at the political level, since major land use decisions are made by the elected government of the day.

But understanding alone is hardly sufficient if not taken into account in an effective land use planning process which the rapidly growing competition for the land resources demands. I have already illustrated the general need to integrate through planning, the principal rural land uses of farming, forestry and water supply. The need is even more pressing in the hinterland of Perth, with its urban residential and industrial growth. For example, between Perth and Bunbury there are already four alumina refineries established or under construction which, in addition to their present site areas, and the 450 ha per annum to be mined, will require close to 50 ha of land each year for residue disposal when in full operation; aluminium smelting at one or more site is likely; other industrial developments are increasing and recreation villages and dormitory suburbs are spreading along the coast and around estuaries and inlets. These attractive bodies of water are also affected by agriculture on the coastal plain. Due to generous applications of fertiliser and of water in the irrigation areas, phosphate lost from the soils in drainage accumulates in the inlets, giving rise to eutrophication and growth of algae and phytoplankton (Hodgkin *et al.* 1981).

In these times of public concern for conservation, many land uses are seen as having adverse environmental effects—clearing of forest may lead to deterioration of water quality and salinisation of soils, industry and residential development can destroy natural areas, reduce open space available for public enjoyment, and produce effluents with the potential to cause atmospheric and groundwater pollution. Agriculture too has its adverse effects. However, such interactions can also be viewed in another way, i.e. as one form of land resource use adversely affecting the potential for others, including provision of conservation reserves and national parks. Thus environmental protection can and should be accommodated to a large extent as part of general land-use planning, rather than be left as an institutionalised after-thought achieved through present requirments for environmental impact statements and environmental review and management programmes.

Strategic planning for the allocation of land resources cannot take place only at the local level. Yet beyond the Perth Metropolitan Region there are no statutory provisions for planning or zoning of land uses at the regional level. The absence of statutory regional land use planning over much of this area does not mean, however, that there is no planning at all. There are something like 95 statutes, 12 government departments, and 20 authorities of various kinds besides local authorities, concerned with land use planning in south-western Australia (Hohnen 1976). While there is some degree of co-ordination by such agencies as the Town Planning Board, the Environmental Protection Authority and the Department of Resources Development, the situation is obviously complex and likely to contain inconsistencies, so that it can hardly be said to provide a proper framework of policy within which individuals as well as government and other agencies can conduct their business with some degree of certainty. An adequate system of land use planning would allocate resources and locate industries with due consideration for the technical factors involved in land resource management. Without it, our increasing understanding of soils and other natural resource systems is unlikely to be fully exploited.

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